The Director General

Maisons-Alfort, 1 October 2014

Revised OPINION
of the French Agency for Food, Environmental and Occupational Health & Safety

concerning the "Health effects related to occupational exposure to breathing gas mixtures other than air in the context of hyperbaric activities",
annuls and replaces the Opinion dated 8 September 2014[1]

ANSES undertakes independent and pluralistic scientific expert assessments.
ANSES primarily ensures environmental, occupational and food safety as well as assessing the potential health risks they may entail.
It also contributes to the protection of the health and welfare of animals, the protection of plant health and the evaluation of the nutritional characteristics of food.
It provides the competent authorities with all necessary information concerning these risks as well as the requisite expertise and scientific and technical support for drafting legislative and statutory provisions and implementing risk management strategies (Article L.1313-1 of the French Public Health Code).
Its opinions are made public.
This opinion is a translation of the original French version. In the event of any discrepancy or ambiguity the French language text dated 1 October 2014 shall prevail.

On 14 February 2013, ANSES received a formal request from the French Directorate General for Labour (DGT) to carry out an expert appraisal on: the health effects related to occupational exposure to breathing gas mixtures other than air in the context of hyperbaric activities.

1. BACKGROUND AND PURPOSE OF THE REQUEST

Former regulations for workers in hyperbaric conditions were stipulated in Decree No. 90-277 dated 28 March 1990 and the corresponding implementation orders, specifically the Order dated 15 May 1992 defining procedures for work in hyperbaric environments including access, durations, exits, and organisation. These regulations, which were strongly influenced by the underwater works activities of, had become difficult to apply in other sectors of activity, particularly scientific and technical settings. A new Decree was therefore published on 11 January 2011 (Decree No. 2011-45). It aimed not only to improve the safety of workers operating in hyperbaric conditions but also to define a common regulatory framework that would harmonise as far as possible the technical rules applicable to the various hyperbaric activities, specifically to improve readability. Orders for each of these sectors of activity are currently being prepared and indicate the specific provisions that are unique to each sector. Several supplemental Orders[2] to the decree have been published since then and govern activities in Sectors A and B.

[1] See Annex 1.

[2] Order dated 30 October 2012 defining procedures for access, durations, exits, and organisation of work in hyperbaric conditions executed with immersion, within Area B "methods, sciences and other operations". NOR: ETST1229456A, ORF No. 0266 dated 15 November 2012, page 18067 text No. 20.
Order dated 30 October 2012 concerning underwater operations carried out in a hyperbaric environment (Area A). NOR: ETST1229420A, ORF No. 0290 dated 13 December 2012, page 19490 text No. 32.

These new regulations include improvements in occupational risk prevention but do not provide specific provisions for the use of new techniques (diving using rebreathers) or techniques not covered by the former regulatory provisions (apnoea).

To ensure that a suitable regulatory framework is established for all these practices, the Directorate General for Labour (DGT) sent a formal request to ANSES on 14 February 2013 for an expert appraisal on the health effects related to occupational exposure to breathing gas mixtures other than air in the context of hyperbaric activities.

With the aim of developing regulations in this wider scope, ANSES was asked to provide information on the following points:

- Identification and characterisation of populations working in hyperbaric conditions for all sectors of activity (tasks, numbers, ages groups, etc.) and conditions of use of equipment and breathing gas mixtures other than air (types of equipment used, gas mixtures used, duration and frequency of use, etc.).
- Definition of the short- and long-term health effects on the human body related to use of the identified equipment and gas mixtures. A specific point of interest is the use of gas recycling devices (rebreathers), for which additional information on practices and uses in other countries as well as international accident statistics are required.
- Analysis of the practice of apnoea as part of professional activities (science, archaeology, fishing, etc.) in order to evaluate accident statistics and physiological consequences, and if necessary, make suitable corresponding recommendations.

The scope of the expert appraisal was determined based on the expectations of the DGT regarding current changes to regulatory texts. The issues of concern for the ministry were primarily the health effects of occupational use of open-circuit diving systems with breathing gas mixtures other than air, the use of rebreathers, and the practice of apnoea (or freediving).
Questions concerning deep-sea saturation diving, which is more limited and very strictly controlled, are not dealt with as part of this expert appraisal, even though they also involve breathing gas mixtures other than air.

2. ORGANISATION OF THE EXPERT APPRAISAL

This expert appraisal was carried out in accordance with the French standard NF X 50-110 "Quality in Expertise - General Requirements of Competence for Expert Appraisals (May 2003)".

The Air Risk Assessment Unit was tasked with conducting this appraisal, with the support of five experts appointed *intuitu personae* specifically for this appraisal. Their areas of expertise are the following: toxicology, physiology, knowledge of professional activities in hyperbaric conditions, knowledge of practices and control procedures for the equipment and breathing gas mixtures used, and hyperbaric medicine, among others.

Collection of data for this expert appraisal relied in part on a literature review (peer-reviewed journals, reference works, or grey literature) and included interviews of stakeholders in the area of professional hyperbaric activities from France and abroad.

The data concerning population profiles and practices specific to each sector were acquired mainly through interviews with professionals in each area of activity. Identified players with relevant knowledge were interviewed through surveys (telephone discussions or email) or through hearings (in person), on the basis of a questionnaire developed jointly by the experts and ANSES in order to respond to the questions raised in the request. The questionnaire aimed to collect data on the

Order dated 31 July 2014 concerning rescue and safety operations in underwater and hyperbaric environments. NOR: INTE1404626A, JORF No. 0185 dated 12 August 2014, page 13483 text No. 44.

professional populations working in hyperbaric conditions (including those practising apnoea), the equipment and breathing gas mixtures used, and the corresponding health effects on the body.

Agencies and national authorities in Europe and North America (United States, Canada) involved in the areas of health and safety and occupational safety were consulted by email in October 2013. This survey mainly helped to determine the legislative framework concerning professional activities in hyperbaric conditions but also provided information on the legislative regulation of rebreathers, the practice of occupational apnoea, and the use and contamination of gas mixtures.

ANSES examines the interests declared by experts before their appointment and throughout the appraisal process in order to avoid any risk of conflict of interests regarding the subjects dealt with as part of the appraisal.

The experts' declarations of interests are made public on the ANSES website (www.anses.fr).

3. AGENCY CONCLUSIONS AND RECOMMENDATIONS

Decree No. 2011-45 dated 11 January 2011 defines hyperbaric conditions as an environment in which workers conduct their professional activities at a relative pressure higher than 100 hPa whether in water or on land. The relative pressure under consideration is defined as the absolute pressure at the airways of the worker at the time when it reaches its maximum value during the professional activity, minus local atmospheric pressure.

▪ Description of areas/practices/populations

Workers in hyperbaric conditions operate in immersed environments (professional divers, scientists, military personnel, rescue personnel, etc.) or with no immersion (tunnel workers, hyperbaric chamber personnel, etc.). Working in hyperbaric conditions requires the worker to adapt to a very specific professional environment.

In France, Decree No. 2011-45 dated 11 January 2011 regulates the practice of professional activities in hyperbaric conditions. To work in a pressurised environment, a worker must hold a certificate of fitness to work in hyperbaric conditions on which the Area and Class specify the type of professional activities undertaken and the pressure zones authorised (depths). Area A concerns underwater activities (deep-sea diving); Area B includes various types of underwater operations such as physical or sport activities, underwater archaeology, defence, civil security, etc.; Area C concerns operations that do not involve immersion of personnel using hyperbaric medical equipment (physicians, nurses, care givers, technicians, etc.); Area D mainly concerns activities without immersion carried out by tunnel workers in tunnel boring.

Although current regulations define the operating methods and breathing gas mixtures authorised depending on the sector of activity, they do not include specific provisions for use of rebreathers or for the practice of apnoea.

This situation appears to be the same in other countries. Following a consultation initiated by ANSES internationally, a number of references were collected, dealing primarily with principles of organisation, responsibility, training, equipment safety, etc. Several texts and standards deal with gas mixtures other than air and with controls aimed at avoiding contamination of gas mixtures or air. Some information was also collected directly or indirectly concerning rebreathers, with contacts indicating that recommendations or instructions applying to materials and equipment apply *de facto* to rebreathers. Lastly, very little information was obtained about monitoring of occupational apnoea.

Based on the data collected from the various players interviewed as part of this expert appraisal, the total number of workers exposed to hyperbaric conditions in France is estimated to be 10,000 people. There is a wide range of sectors of activity, as well as methods of operation in hyperbaric environments, which are specific to each sector.

Activities involving use of breathing gas mixtures other than air

From a health perspective, hyperbaric workers are subject to the risks inherent to their activity in addition to the specific risks related to hyperbaric environments. These specific risks are associated with adaptation of the body to external pressure changes and with variations in the partial pressure of the various inhaled gases. Any change in one or more of these parameters can result in more or less serious disruptions, although there is a certain level of tolerance, or even habituation. As such, an adaptation effect will not necessarily have an adverse effect on the human body. However, exposure to hyperbaric conditions can lead to acute or chronic disease states such as barotrauma, intoxication due to the inhaled gases, decompression sickness, etc., which have varying severity ranging from minor discomfort in the ears to fatal outcomes. These effects develop during or after a period of work at pressure higher than atmospheric pressure. Working conditions in restrictive settings such as underwater or underground environments or welding activities, etc. can also lead to accidents specific to the activity in question.

Irrespective of the Area and the type of operation undertaken, air is the mostly commonly used breathing gas mixture for operations in hyperbaric conditions. Nonetheless, its use is restricted by the physiological constraints related to the toxicity of breathing gases and specifically nitrogen (risk of narcosis, decompression sickness and shortness of breath), along with technical limitations. The risk of nitrogen narcosis becomes significant for all workers who use air from 6 bars of absolute pressure (depth equivalent of 50 metres).

Hyperbaric operations carried out using gas mixtures other than air can compensate for some of the physiological constraints related to diving with air. Regulations define the breathing gases that are authorised for hyperbaric operations and the requirements in terms of composition of these mixtures (maximum partial pressures, maximum concentrations of pollutants). Work using gas mixtures is already highly developed in some sectors of activity within Area B (defence, civil security, speleology, underwater photography and filming, etc.) and using these mixtures in suitable conditions improves safety during the operations.

Many studies have specifically examined the health effects of inhaling pure oxygen in hyperbaric conditions in a professional context, mainly for decompression or medical treatments. There are however fewer published studies that analyse other gas mixtures. Nonetheless, many reference works on the theoretical principles related to the effects of gases provide information on the advantages and disadvantages of gas mixtures from a health perspective.

Use of breathing gas mixtures other than air during hyperbaric operations has the advantage of reducing the risks of narcotic effects related to inert gases, strongly in the case of Heliox. Technically, applying these methods is more costly than using air because of the need to use specific equipment and the fact that supply and manufacture of the mixtures are more complex.

The table below presents the advantages and disadvantages of using gas mixtures other than air from a health perspective and in terms of technical factors and convenience.

Summary table of the properties specific to the composition of each type of mixture

Breathing gas mixture	Health perspective		Technical factors and convenience	
	Advantages vs air	***Disadvantages vs air***	***Advantages vs air***	***Disadvantages vs air***
Decompression stops with pure O_2 and enriched oxygen mixtures	lower risk of decompression sickness (DCS)	risk of hyperoxia (seizures, cardiorespiratory decompensation)	- optimisation of decompression - reduced duration of decompression stops - reduced fatigue - reduced duration at the surface between 2 successive operations	risks of fire when used in a dry atmosphere
NITROX deep mixture (binary N_2/O_2 mixture with 30 to 60% O_2)	- lower risk of DCS - lower risk of narcosis	risk of hyperoxia	- optimisation of decompression (during use of Nitrox following an air decompression profile) - reduced duration of decompression stops - reduced fatigue	lower maximum pressure (or depth) of operation

			- reduced duration at the surface between 2 successive operations	
TRIMIX (ternary N_2/He/O_2 mixture)	- decreased risks: ○ of hyperoxia ○ of hypercapnia - improved breathing performance and reduced risk of shortness of breath	cooling of the body	increased maximum pressure (or depth) of operation	mixtures made of helium: - increased duration of decompression stops - high cost of helium
HELIOX (binary He/O_2mixture)	improved breathing performance and reduced risk of shortness of breath	- cooling of the body - risks of narcotic effects related to helium for operating depths greater than 200 metres: nausea, dizziness, tremor, auditory hallucinations, EEG changes, etc.	significant increased maximum pressure (or depth) of operation	

- **Activities using rebreathers**

Rebreathers are self-contained devices for use in hyperbaric conditions that recover exhaled gases in order to reuse them. In this way, workers do not need to have several gas tanks. They provide workers with greater autonomy and ease-of-use compared to open-circuit systems and have several other advantages depending on their method of operation (closed- or semi-closed circuit, mechanical or electronic control): increased working time under pressure, stabilisation of oxygen partial pressure, reduced thermal constraints, etc. The limitations of these devices in terms of safety of use mainly concern the electronic management of operation parameters, which may affect worker attention and can sometimes malfunction (solenoid and oxygen cells, specifically).

In terms of health effects, aside from decompression sickness (DCS) and barotrauma whose occurrence is generally irrespective of the type of breathing system used, there are other accidents that can occur during activities in hyperbaric conditions directly related to the use of mixtures or rebreathers. Most of these accidents are biochemical (hypoxia, hyperoxia and hypercapnia) and are most often related to a malfunction of the rebreather or non-compliance with recommendations for use of the equipment by the worker. The most significant risk of biochemical accidents is loss of consciousness. In an underwater environment, this can lead to drowning, almost always with a fatal outcome in the absence of specific precautions. Use of rebreathers may also involve a higher risk of immersion cardiovascular events.

Use of rebreathers is not covered by regulations, which explains why their use is still limited. Some sectors of activity in Area B such as defence, speleology and underwater photography-filming have nonetheless started using this type of equipment. Use of this system during conventional diving could be beneficial in terms of safety because it prolongs the duration of survival in the event of an incident and makes it easier to manage incidents, even at great depths, for instance enabling a diver to return to the vessel or diving bubble, in order to be brought to the surface.

There are few bibliographic references on accidents or on the acute or chronic effects of using rebreathers in a professional context. Data are available but mainly concern activities of the French Navy. An analysis of accidents related to use of rebreathers and gas mixtures within the French Navy over a period of about 20 years was used to calculate the estimated risk of accidents at 1 in 6,000 dives. The most common accidents are biochemical (60% of all accidents, with 40% hypercapnia, 30% hyperoxia and 30% hypoxia) and occur irrespective of the type of rebreather, followed by DCS (15%: recorded with use of 40% Nitrox or 30% O_2 mixtures), which are far less common than during air diving. Over the 20 years under assessment, three deaths were recorded: two with pure oxygen and one with a ternary mixture. The military personnel population is characterised by its young age, good physical condition, strict procedures and discipline in

execution. Moreover, the types of activities were primarily square dives[3]. It is therefore difficult to extrapolate these data to other sectors of activity in which diving takes place in a very different context.

▪ Activities in apnoea

Apnoea is fundamentally different from diving with a scuba set. In an occupational setting, its use is still occasional but it is becoming more common for activities within Area B for various operations such as visual inspection of the state of breeding cages for fish at sea, clam fishing, ichthyologic research of underwater fauna, and underwater sample collection by scientists. The main advantage of apnoea is its flexibility. Apnoea diving is rapid and easy to implement because it requires very few logistics. The main constraint of working in apnoea is that the duration and depth of dives are limited.

Currently, the decree does not stipulate any training or specific aptitude for practicing professional apnoea. Practising apnoea in an occupational setting is only authorised for workers who are classified in Area B and provided that the relative exposure pressure is not higher than 1,000 hPa (10 metres depth) (with the exception of professional monitors for recreational diving who must follow the specific provisions of the French Sports Code). Given the unique nature of this practice, it should be possible to perform it without any qualification in scuba diving.

Apnoea diving does not expose the diver to the same risks as those involved in diving with air tanks and can lead to specific disease states. A major accident characterises this practice: syncope. This results in loss of consciousness potentially complicated by drowning in the absence of backup and of itself justifies all the preventive safety measures taught and applied for this activity. Freedivers are also subject to the risk of barotrauma (lungs, ears, sinuses, face, teeth, and gastrointestinal tract), immersion cardiovascular events, hypercapnia, and neurological events (a form of stroke). The mechanisms underlying these events are still poorly understood.

There are currently few studies or bibliographic references on the long-term effects related to the practice of apnoea as a professional activity.

ANSES concludes that some of the information collected as part of this expert appraisal points to new prospects offered by gas mixtures other than air, rebreathers, and apnoea in professional activities conducted in hyperbaric environments. However, these practices carry specific risks for the health of workers and therefore require recommendations in terms of equipment, training, and procedures. **The various reported accidents have occurred as a result of a combination of multiple factors**: most importantly, the type of gases making up the breathing mixture, the pressure at which these gases are to be used, and the type of equipment used, along with the environmental conditions of the activity and the health of the worker performing the task.

[3] Descent directly to a given maximum depth for a specific duration with little change in depth.

In accordance with the expectations of the DGT regarding its request for support to develop a regulatory framework and on the basis of proposals from the experts, ANSES has established a set of recommendations intended to improve the safety and comfort of workers during operations in hyperbaric conditions. The recommendations have been ranked in order to highlight priority action items. With decreasing importance, three levels were associated with each proposal, depending on whether it is 1) strongly recommended, 2) recommended, or 3) advised.

- **Recommendations in terms of prevention**

GENERAL REMARKS ON ACTIVITIES IN HYPERBARIC CONDITIONS

- For all areas, it is recommended that the use of air above 6 bars of absolute pressure (depth equivalent: 50 metres) be avoided, in order to reduce the significant risk of narcosis. Use of gas mixtures other than air is therefore strongly recommended in these conditions.
- However, in the event of operations using air between 6 and 7 bars of absolute pressure (depth equivalent: 50 and 60 metres)[4], in order to reduce the risk of decompression sickness (DCS), it is strongly recommended that workers:
  - do not exceed 10 minutes work time;
  - carry out a pure oxygen stop at 1.6 bar of absolute pressure (depth of 6 metres).
- To ensure traceability of operations and accidents in professional hyperbaric contexts:
  - It is strongly recommended that a specific section be added to the worker's journal of operations or tasks in hyperbaric conditions, concerning the use of mixtures, rebreathers, and apnoea with specific accident reporting, risk practices, equipment malfunctions, and short- and long-term health effects;
  - It is recommended that a national database be established to record all exposure parameters and accidents occurring during professional hyperbaric activities. Analysis of these data recorded in the database should be carried out in the form of feedback associated with a quality assurance process.
- It is recommended that the competent authorities organise monitoring in the field of implementation of suitable supervision for the use of rebreathers and mixtures, with priority monitoring for mixtures containing helium.

[4] Exceptional operating situations and work carried out in hyperbaric environments provided for in Article R. 4461-49 of Decree No. 2011-45 dated 11 January 2011.

ACTIVITIES USING BREATHING GAS MIXTURES OTHER THAN AIR

ACTIVITIES USING MIXTURES OF ALL TYPES

- It is strongly recommended for all areas that mixtures other than air be used for any operation above 6 bars of absolute pressure (depth equivalent: 50 metres).
- In order to avoid decompression sickness, it is strongly recommended that workers limit the number of operations under pressure:
  - to one per day for all operations using mixtures carried out at absolute pressure above 6 bars;
  - to two per day for all operations carried out at between 6 and 7 bars of absolute pressure with decompression stops for Nitrox mixtures, provided that there is a hyperbaric chamber and that medical or paramedical personnel competent in hyperbaric medicine are present at the site.
- It is strongly recommended that the maximum authorised pressure be limited to 10 bars of absolute pressure (depth of 90 metres) for operations using mixtures in scuba systems (open-circuit or rebreathers). Above this level, these operations can be carried out on a case-by-case basis after approval is obtained from the competent authorities.
- It is strongly recommended that training programmes be adapted to train workers on operations using mixtures for professional implementation of this practice, within certified/accredited organisations. When accreditation or certification is granted to these organisations, the competent authorities must ensure that the necessary prerequisites are in place to include this specific training.
- It is strongly recommended that European standards be applied that define the equipment and materials used during operations with gas mixtures:
  - NF EN 144-3: 2003 / Respiratory protective devices - Gas cylinder valves - Part 3: Outlet connections for diving gases Nitrox and oxygen;
  - NF EN 13949: 2003 / Respiratory equipment - Open-circuit self-contained diving apparatus for use with Nitrox and oxygen - Requirements, testing, marking, etc);
  - NF EN 15333-1: 2011 / Respiratory equipment. Open-circuit umbilical supplied gas diving apparatus. Part 1: Demand apparatus;
  - NF EN 15333-2: 2011 / Respiratory equipment. Open-circuit umbilical supplied gas diving apparatus. Part 2: Free flow apparatus.
- For operations using oxygen enriched mixtures, it is strongly recommended that "oxygen-grade" equipment be used (as defined in Standard NF EN 144-3: 2003 which specifies that cleaning products for the equipment must be compatible with the use of oxygen).
- It is recommended that ready-to-use mixtures (labelled and analysed by the supplier) be given priority.
- In the event of transfer of ready-to-use gas mixtures from the original container to another container, it is strongly recommended that the operator checks compliance of the transferred mixtures with the characteristics of the initial mixture (percentage of gases in the mixture).
- In the event of preparation of gas mixtures, it is strongly recommended that the operator allow the mixture to stand for 12h after preparation (time required to obtain a stable gas mixture) before checking the percentage of gases in the mixture and carrying out final labelling.

- It is strongly recommended that specific procedures be complied with when using mixtures:
  - **Before the operation**
    - Selecting a mixture suitable for the pressure of the operation;
    - Checking the percentage of O_2 in the mixture in the tank with traceability in the log book and labelling of the tank;
    - Fitting specific regulators for the mixtures on the tank;
    - Planning and implementing a timetable for use of the different gas mixtures during the operation (run time) and determining the maximum depth;
    - Selecting a decompression tool and adjusting the percentage of O_2 if a computer is used.
  - **During the operation**
    - Complying with the timetable for use of the various gas mixtures, the maximum depth, the duration at the maximum depth of the operation, and the decompression profile;
    - Reducing strain;
    - Repeated verification of the PpO_2 of the inhaled mixture if a rebreather is used at constant PpO_2.
  - **After the operation**
    - Storing specific equipment for use with mixtures, not mixing with routine equipment;
    - Filling in the report sheet specific to gas mixtures.

ACTIVITIES WITH BINARY N_2/O_2 MIXTURES (NITROX)

Binary N_2/O_2 or Nitrox mixtures refer to enriched air mixtures, i.e. those with an oxygen content exceeding 21%. Depending on the percentage of O_2 that they contain, these mixtures could be used as “deep” gases or as decompression gases.
Compared to air, use of Nitrox mixtures helps to optimise decompression when it is used with an air decompression profile and a reduction in the duration of immersion in restrictive environments.

Use of "deep" gas: Nitrox with 30 to 60% O_2 // PpO_2 limited to 1.4 bar

- Use of Nitrox as a deep gas is recommended for:
  - "yoyo" profiles (Cartesian principle);
  - repeated operations;
  - operations with decompression stops;
  - operations at high altitude;
  - during intense physical effort.

Moreover, Nitrox has the advantage of being easy to manufacture compared to ternary mixtures.

Use in decompression: Nitrox at over 80% O_2 // PpO_2 limited to 1.6 bar

- Use of Nitrox in decompression is recommended during:
  - operations at high pressure (from 5 bars, i.e. depth equivalent: 40 metres), paying attention to limiting risks related to oxygen toxicity;
  - operations with decompression stops;
  - operations requiring intensive physical effort;
  - recovery procedures following a rapid ascent speed or a shortened decompression stop.

ACTIVITIES WITH BINARY He/O_2 MIXTURES (HELIOX)

Binary He/O_2 mixtures or Heliox refer to mixtures containing oxygen and helium.

- For operations at absolute pressures higher than 8 bars or for deep diving (below 70 metres), use of Heliox mixtures is advised rather than ternary mixtures, because:
  - a validated decompression table is available for these operating profiles;
  - Heliox has the advantage of being easy to manufacture compared to ternary mixtures.

ACTIVITIES WITH TERNARY N_2/He/O_2 MIXTURES (TRIMIX)

Ternary N_2/He/O_2 mixtures or Trimix refer to breathing mixtures that contain oxygen, nitrogen, and helium.

- Use of Trimix mixtures is recommended from 6 bars of absolute pressure (depth equivalent: 50 metres).

DECOMPRESSION WITH PURE O_2

- Making use of decompression stops with pure oxygen is strongly recommended:
  - for operations at high pressure (from 5 bars, i.e. depth equivalent: 40 metres);
  - for operations with decompression stops;
  - for operations requiring intensive physical effort;
  - for operations in Area C;
  - during recovery procedures after rapid return speed to atmospheric pressure (i.e. 1 bar of absolute pressure) or a shortened decompression stop.
- In underwater environments, it is strongly recommended to carry out stops using a fixed or mobile decompression line.

DECOMPRESSION TOOLS

Use of breathing mixtures by professionals working in hyperbaric conditions requires that the competent authorities provide validated decompression tools for use in an occupational setting.

It is therefore strongly recommended that:

- a method be defined to validate decompression tools for use of gas mixtures in an occupational setting, or failing that to propose decompression models.
- in the interim, define criteria to enable use of existing decompression tools.

EQUIPMENT

- It is strongly recommended that operating equipment for hyperbaric conditions be harmonised within a given company, particularly equipment associated with breathing gases (regulators and decompression computers with the same characteristics and that are suitable for the operating environments).
- It is strongly recommended that operating techniques on a hyperbaric site be standardised, concerning both breathing gases and the equipment used. This is because multiple operating methods on the same site to perform the same task are a source of accidents.
- To ensure prevention of transmissible diseases caused by certain microorganisms (staphylococci, tuberculosis, herpes, hepatitis, amoebas, candidiasis, etc.), it is recommended that disinfection protocols suitable for the operating conditions be implemented for breathing equipment.

OPERATIONS WITH OPEN-CIRCUIT SCUBA EQUIPMENT

- When using open-circuit scuba equipment, use of "deep" Nitrox mixtures should be preferred if possible since these mixtures help to improve safety (reduced decompression, greater diving comfort, less fatigue, etc.).
- For operations above 10 bars of absolute pressure (depth equivalent: 90 metres), use of open-circuit scuba equipment is not suitable. Use of rebreathers can be considered, but diving with a vessel should be given preference, particularly for workers in Area A.

ACTIVITIES WITH REBREATHERS

- For operations that require discretion, high gas autonomy, thermal comfort or optimisation of decompression, use of a rebreather is advisable.
- For operations higher than 10 bars of absolute pressure (depth equivalent: 90 metres), it is strongly recommended that use of vessels be preferred for human intervention, or a robot that can be remote-controlled from the surface (remote-operated vehicle or ROV). If this is not possible, it is recommended that open-circuit systems be replaced by rebreathers accredited for the maximum depth of the operation.
- At high absolute pressure, particularly offshore but also in deep tunnels, a rebreather can be advised as a backup to guarantee sufficient autonomy to reach the vessel in the event of a malfunction concerning supply of respiratory fluids.
- It is strongly recommended that specific training be implemented and given by a certified/accredited organisation with:
  - initial training on the specific rebreather (closed, semi-closed), for use in an occupational setting;
  - further training on the specific apparatus made available by the employer and suited to the tasks to be undertaken by the worker.
- It is strongly recommended that training be carried out to maintain abilities and knowledge, at least every 5 years.
- It is strongly recommended that the work position and type of task be defined before choosing the rebreather to ensure the greatest possible ease of use at the work station.
- Concerning availability of rebreathers within a company, it is strongly recommended that the employer:
  - give preference to individual equipment (1 rebreather for each worker) to reduce risks related to maintenance and preparation of the equipment before use (specifically refilling with soda lime);
  - at a minimum, the worker must always prepare the apparatus that he or she will use once operational (commissioning and reconditioning the apparatus).
- It is strongly recommended that the instructions for operation, cleaning, and maintenance of the apparatus as defined by the manufacturer be strictly complied with.
- It is strongly recommended that specific diving safety measures be applied:
  - limit tasks that require intensive physical effort or bulky tools to prevent the risk of hypercapnia;
  - systematically work in pairs with the same type of apparatus, mixture, and decompression procedure;
  - always use a nozzle strap and a lip cover to maintain the system (mouth piece) in place in the event of loss of consciousness to prevent the risk of drowning;

- implement redundancy in open circuits on equipment, supplied with mixtures that can be used at the maximum depth of the operation or at least, ensure redundancy by a second rebreather.

➢ It is strongly recommended that divers are active on a regular basis, with at least two dives per month to maintain their skills.

➢ In the event of long-term interruption (for more than one month), it is recommended that a procedure for accompanied return to diving work be established and that workers gradually increase operating depths.

APNOEA

➢ Given the unique characteristics of apnoea, it is strongly recommended that the provisions governing the practice of apnoea in an occupational setting be distinguished from those governing other types of operations taking place in professional hyperbaric contexts. It could be beneficial to develop a specific Area for the practice of professional apnoea, associated with distinct techniques and specific training.

➢ The practice of apnoea in an occupational setting can be considered provided that the following safety requirements are strictly adhered to:

- In the operating zone from 0 to 20 metres, it is strongly recommended that two depth levels be defined, to which different safety and monitoring rules should be applied:
  - Level 1: from 0 to 10 metres;
  - Level 2: from 10 to 20 metres.
- Below 20 metres, it is strongly recommended that operations using apnoea be avoided, with the exception of training monitors, exemptions, or specific measures.
- It is strongly recommended that diving be carried out in pairs with visual contact:
  - for depths greater than 10 metres, both divers must necessarily be in the water to ensure constant visual monitoring.
  - for depths less than 10 metres, an operation with a single diver in apnoea can be considered provided that a specific procedure, an alert system, and a means of localisation are set up, and that a flotation device is available nearby.
- It is strongly recommended that the apnoea dive last no more than 90 seconds, particularly for depths of more than 10 metres.
- It is strongly recommended that the depth of operation and the duration of daily immersion be adjusted based on temperature. The maximum recommended duration is 5 hours. This duration is reduced to 3 hours when the water temperature is below 12°C[5].
- It is strongly recommended that:
  - apnoea diving should not be carried out less than 12 hours after an operation in a hyperbaric setting with decompression stops;
  - operations should be planned based on the tasks to perform, the characteristics of the site, the equipment available, and the specific environmental conditions;

[5] The selection of durations is based on evaluation of scientific data concerning loss of heat associated with decreases in water temperature and on experience reported by apnoea divers.

- warm-ups and gradual immersion should be performed;
- prolonged hyperventilation (more than 4 broad movements in 15 seconds) should be avoided before an apnoea dive;
- deep apnoea at low lung volume should be avoided;
- ”lung packing” (or "glossopharyngeal insufflations”)[6]; should be limited
- diaphragm contractions should be used with caution at depth;
- high-intensity exercises should be avoided during ascent;
- blackouts and loss of motor control (samba)[7] should be taken seriously;
- recovery time should be as long as the apnoea time;
- divers should hydrate themselves to compensate for water losses of about 300 mL per hour of immersion;
- intake of aspirin should be avoided during periods of apnoea diving;
- apnoea dives taking place less than 12 hours before an operation in a hyperbaric setting should be considered a full scuba operation (maximum depth, duration of work).

- **Recommendations in terms of research and development**

➢ Ensure long-term follow-up of workers who use mixtures and rebreathers, as well as professional freedivers, to obtain additional data on the potential associated health effects.

➢ Continue the development and qualification of compression algorithms that can be adapted depending on the environmental parameters of the operations and the individual characteristics of the workers.

➢ Continue research concerning analysis and control systems, particularly for rebreathers (improving oxygen cells, reliability of CO_2 analysers, etc.).

Marc Mortureux

[6] A glossopharyngeal insufflation manoeuvre that mimics the mouth movements of the carp fish with the aim of distending the chest as much as possible to increase intrapulmonary volume and pressure.

[7] Toxicity-related accident associated with hypoxia manifesting as uncoordinated movements and transient alertness disorders.

KEY WORDS

Hyperbaric conditions, occupational exposure, breathing gas mixtures, health effects, health risks, rebreather/gas recycling apparatus, apnoea.

GLOSSARY

Biochemical accident: accident related to increases in partial pressures of breathing gases in which toxicity thresholds of these gases are exceeded through an increase in the absolute pressure during operations in hyperbaric conditions.

Immersion cardiovascular accident: diving accident in scuba or apnoea conditions that is multifactorial and related to immersion constraints. It most often involves acute immersion pulmonary oedema characterised by development of capillary and alveolar endothelial lesions due to immersion and causing irruption of pulmonary capillary content into the alveoli.

Decompression sickness: a disorder related to chaotic formation of gas bubbles in body tissues resulting in tissue lesions or vascular obstruction. These accidents are often related to decompression speeds that are too rapid and occur during decompression or after being in high pressure conditions.

Barotrauma: damage caused by pressure and therefore volume changes in the air cavities of the human body (natural: sinus, middle ear, lungs, stomach, intestines and/or pathological: dental caries, emphysema, etc.). Barotrauma accidents may occur during the compression or decompression phases.

Hypercapnia: increased or excess CO_2 in the blood. The symptoms of hypercapnia increase in severity with increases in CO_2 partial pressure (hyperventilation, breathlessness, then loss of consciousness).

Hyperoxia: excess supply of O_2 in the body that is likely to cause neurological or even pulmonary damage if it occurs for a long period of time.

Hypoxia: drop in the partial pressure of oxygen in the body below 110 to 130 hPa and that may rapidly lead to loss of consciousness depending on individual sensitivity.

Nitrogen narcosis: altered mental processes with manifestations ranging from mild euphoria to loss of consciousness.

Syncope: brief loss of consciousness.

ANNEX 1: OPINION UPDATES

Date	Version	Page	Description of changes
08/09/2014	01		First signed version of ANSES opinion
22/09/2014	02	7	Following discussions with the DGT during the feedback meeting held on 17 September 2014, the wording of the following recommendation was amended: *"It is recommended that the competent authorities implement specific audits for professional hyperbaric activities in order to check in the field that regulations are properly applied"* and replaced by *"It is recommended that the competent authorities organise monitoring in the field of implementation of suitable supervision for the use of rebreathers and mixtures, with priority monitoring for mixtures containing helium*".
		16	A glossary defining the main medical terms used in the expert appraisal was added to the opinion.